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White Paper
On the Use of Simulation to Analyze the Capability of the Space Shuttle to Complete the Construction of the International Space Station

by
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Topic Areas: Affordability, Modeling and Testing

1. Background

Kennedy Space Center (KSC) has developed a rich set of modeling and simulation tools for analyzing current and future space transportation system concepts. Two of these tools are GEM-FLO and Shuttle-Ops. GEM-FLO (**G**eneric Simulation **E**nvironment for **M**odeling **F**uture **L**aunch **O**perations) can model both current and future space transportation systems, including reusable or expendable elements and combinations thereof. The [1]Shuttle-Ops tool is a simulation specific to the current US Space Shuttle operation, offering greater detail than the generic GEM-FLO tool.

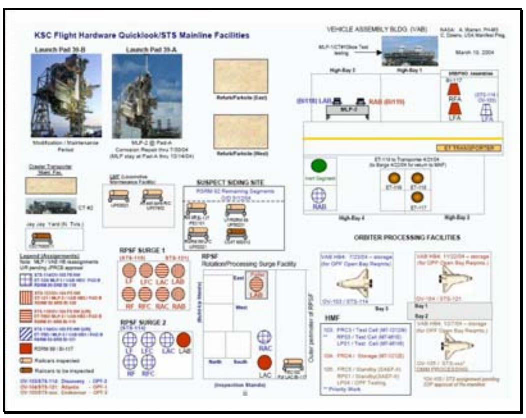

Figure 1: Shuttle Flight and Ground Infrastructure, Sample Scheduling Overview by Shuttle Operations Prime Contractor United Space Alliance (USA)

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[1] "Modeling the Space Shuttle", Proceedings of the 2002 Winter Simulation Conference, Orlando FL, Cates, G.R., Steele, M.J., NASA Kennedy Space Center, Mollghasemi, M., Rabadi, G., University of Central Florida

2. Objective

This analysis uses GEM-FLO and Shuttle-Ops to analyze the capability of the Space Shuttle fleet and ground infrastructure (**Figure 1**) to complete the construction of the International Space Station.

3. The Baseline Case

GEM-FLO 2.0 runs a Visual Basic Graphic User Interface (GUI) (**Figure 2** and **Figure 3**) that connects and populates the underlying simulation running in Rockwell Arena © software (version 7.0). GEM-FLO was developed through collaboration between the University of Central Florida (UCF), KSC, Dr. Martin Steele, and Grant Cates, and Orlando small business Productivity Apex Inc. headed by Dr. Mansooreh Mollaghasemi.

The model has undergone extensive validation and verification (2000-2003). A first blush scenario runs a baseline, a Shuttle scenario pre-Columbia, with the simulation based on existing infrastructure, 4 orbiters (Columbia, Discovery, Atlantis and Endeavour) and the historical data distributions for ground processing times.

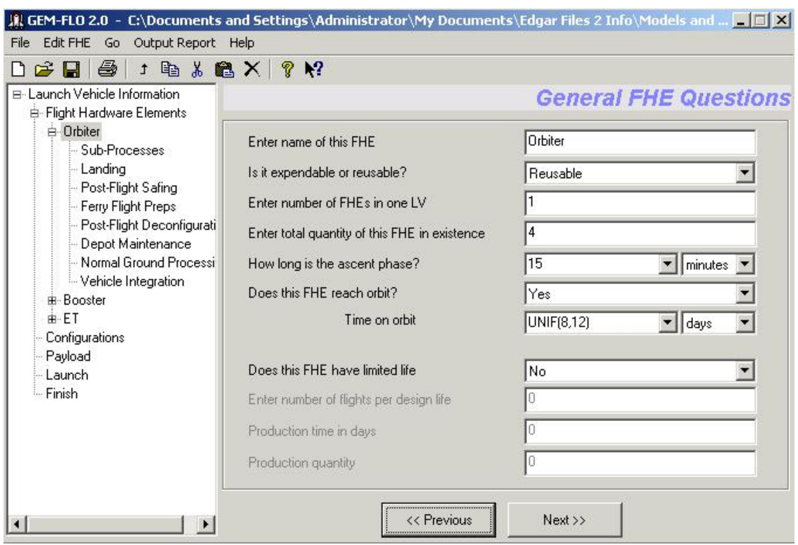


Figure 2: GEM-FLO Input Screen, Basic Variables

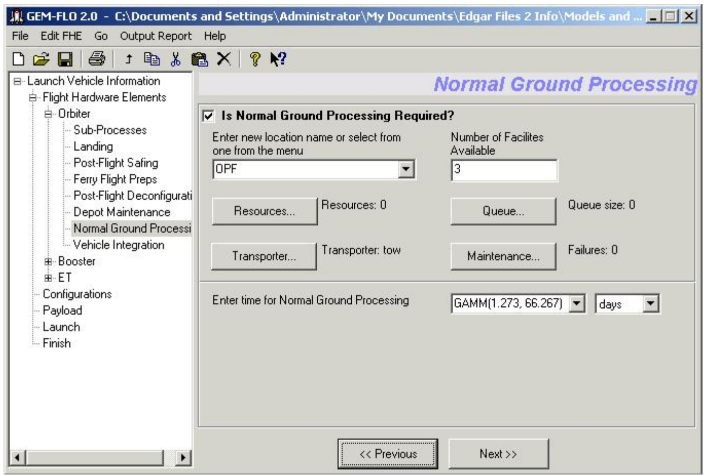


Figure 3: GEM-FLO Input Screen, Specifying Distribution Curves Based on Historical Performance, for this Step "GAMM (1.273, 66.267)"The baseline infrastructure includes 3 Orbiter Processing Facilities (OPF), 2 integration cells in the Vehicle Assembly Building (VAB), and 2 launch pads, Launch Complexes 39 A and B. The orbiter overhauls, or Orbiter Maintenance Down Period (OMDP), occurs in California every 8 flights for any one orbiter. These variables and others represent the pre-Columbia / STS-107 Space Shuttle fleet.

Additionally, the model variable "Percentage Loss of Vehicle (LOV)" accounts for ascent and descent losses as well as various abort scenarios. The baseline Shuttle file for the GEM-FLO model sets these values for LOV at 0.207 for both ascent and descent. This value of 0.207 translates roughly into a 1/483 probability of a loss of vehicle on ascent and on descent, equal to a 1/241 probability of loss of vehicle across the flight regime. Other similar variables are shown in **Figure 4**.

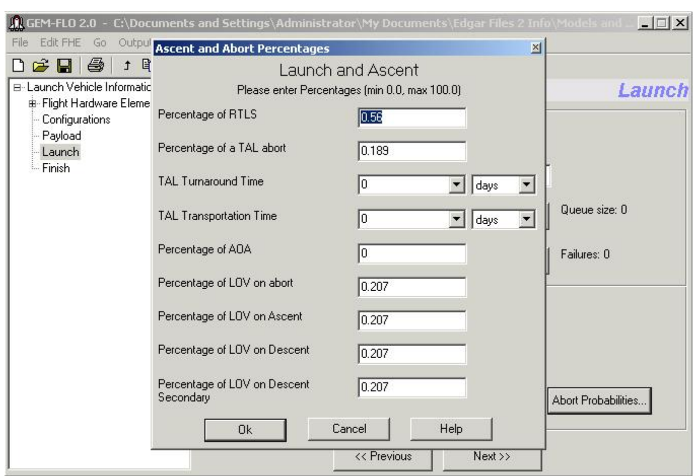


Figure 4: Baseline GEM-FLO model file settings for various loss of vehicle factors

The exact value for a loss of vehicle probability receives endless debate. Knowledge or certainty about a value does not affect the ability to gain valuable insight from a simulation. Analysts may simply use a range of values and examine "what if". **Figure 5** shows the results when the model baseline settings include or do not include a possibility of losing a vehicle. In both cases the flight rate approximates the historical data extremely well. The case where the loss of vehicle or abort mode variables are zero provides outputs results where confidence intervals overlap the historical data used to construct the model.

GEM-FLO Case Runs March 24, 2004

Scenario>	Historical Data, Flight Rate per Year Mean	Baseline Model, with Loss of Vehicle Settings and Abort Modes Allowed	(A) Baseline Model, with Loss of Vehicle Settings and Abort Modes NOT Allowed
Settings			
Replications, # of Runs		30	30
Run Length (X Days)		5475	5475
Warm up (X Days)		1825	1825
Mission Request Arrival Frequency (Every X Days)		30	30
Outputs			
Flights, # of, Over the Entire Run Length		68.9	72.7
Flights per year, Simple Average	**7.17**	6.89	7.27
Half Width, for # of Flights over the Entire Run		3	0.48
95% Confidence Interval	**6.7, 7.6**	**6.59, 7.19**	**7.22, 7.32**
Minimum # of Flights During the Run		39	69
Maximum # of Flights During the Run		76	75
Half Width Test, Flight Rate, (<10% PASS=GREEN)		4.35%	0.66%

Complete Overlap

Figure 5: Baseline Simulation (GEM-FLO) Results for Shuttle with and without Loss of Vehicle Probability

4. Post-Columbia / STS-107

4.1. Case 1 – A Three Orbiter Fleet

GEM-FLO was developed and in use before STS-107. As such, analysts had already run multiple scenarios applicable to a 3 orbiter fleet. Post-Columbia analysis can refine and better adjust scenario analysis to the current situation.

Keeping "loss of vehicle" inactive in the model, three orbiters rather than 4 are specified (**Figure 6**) resulting in the values tabulated in **Figure 7**. Given the constraint of a fleet limited to 3 orbiters, approximately 5 and ½ flights per year can be achieved.

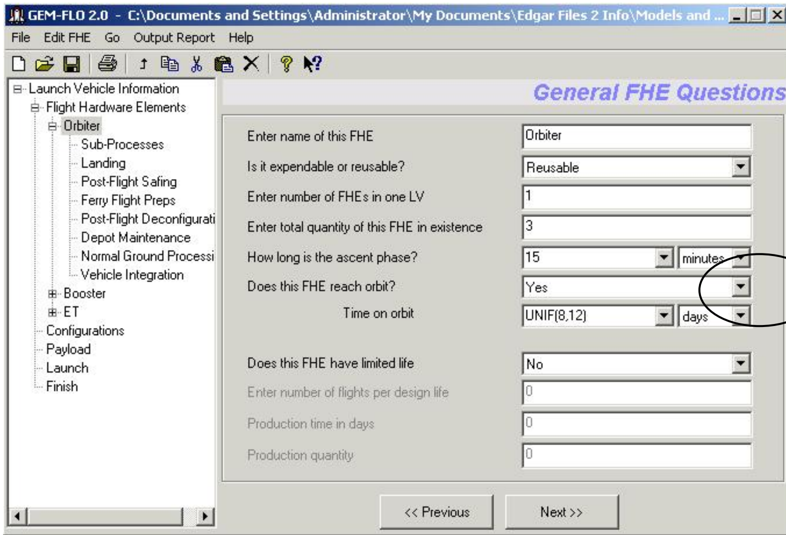


Figure 6: Model with Only 3 Orbiters in the Fleet, Same Infrastructure

GEM-FLO Case Runs March 24, 2004

Scenario>	Historical Data, Flight Rate per Year Mean	Baseline Model, with Loss of Vehicle Settings and Abort Modes Allowed	(A) Baseline Model, with Loss of Vehicle Settings and Abort Modes NOT Allowed	Case 1 - Same as "(A)" But 3 Orbiters in the Fleet Rather than 4
Settings				
Replications, # of Runs		30	30	30
Run Length (X Days)		5475	5475	5475
Warm up (X Days)		1825	1825	1825
Mission Request Arrival Frequency (Every X Days)		30	30	30
Outputs				
Flights, # of, Over the Entire Run Length		68.9	72.7	54.9
Flights per year, Simple Average	**7.17**	6.89	7.27	5.49
Half Width, for # of Flights over the Entire Run		3	0.48	0.34
95% Confidence Interval	**6.7, 7.6**	**6.59, 7.19**	**7.22, 7.32**	
Minimum # of Flights During the Run		39	69	53
Maximum # of Flights During the Run		76	75	56
Half Width Test, Flight Rate, (<10% PASS=GREEN)		4.35%	0.66%	0.62%

Figure 7: A 3 Orbiter Space Shuttle Fleet, with all Past Variables, such as Processing Times, Held Constant; Approximately 5 and ½ Flights per Year Results, a Value Constrained by the Number of Orbiters Available

5. Completing the International Space Station

The simplified Case 1 estimate leads to the date values tabulated in **Figure 8** for completing the International Space Station based on the number of launches required. The simulation sets the Shuttle in motion so to speak, based on historical probabilities, run repeatedly across many samplings. Because of this, the model does not present a certain date for a certain launch. Rather, the models probabilistic nature simply states the likely outcome *over time*.

At first glance the value of ~ 5.5 launches per year (Figure 7) supports the ability of the Space Shuttle, ***assuming resumption of flights early in 2005***, to complete the ISS by the timeline expressed in the 2004 Presidential Vision for Space Exploration.

Basis: GEM-FLO Model Approximation *Simplified Case 1*	**Approximate ISS Completion Using a 3 Orbiter Fleet, Assuming Launch Resumption Early 2005**
20 Launches	2008
25 launches	2009
27 launches	**2009**
30 launches	2010

Figure 8: Model Results Using Un-changed, Baseline Historical Probabilities Indicate these Approximate Completion Dates for the ISS Using a 3 Orbiter Space Shuttle Fleet

5.1. Case 2 – The "10 / 1 / 3" Scenario

Case 2 represents a scenario where certain post Columbia factors are explored. The orbiter periodic overhauls will now occur locally at KSC, rather than in California, eliminating ferry flight delays.

More significantly, additional processing days are modeled quickly by a simple "what if" method based on awareness that a post Columbia ground processing posture will have added constraints other than the sole factor of the absence of Columbia as a flight asset.

Beginning Case 2 a slight up-tick occurs in the flight rate. The overhaul at KSC boosts flight rate, but not significantly (using the term here loosely). The values tabulated in **Figure 9** show the baseline flight rate now at just over 5 and ½ flights per year for a 3 orbiter fleet.

GEM-FLO Case Runs March 24, 2004			(A)		
Scenario>	Historical Data, Flight Rate per Year Mean	Baseline Model, with Loss of Vehicle Settings and Abort Modes Allowed	Baseline Model, with Loss of Vehicle Settings and Abort Modes NOT Allowed	Case 1 - Same as "(A)" But 3 Orbiters in the Fleet Rather than 4	< Same, But Periodic Overhaul now at KSC (not California).
Settings					
Replications, # of Runs		30	30	30	30
Run Length (X Days)		5475	5475	5475	5475
Warm up (X Days)		1825	1825	1825	1825
Mission Request Arrival Frequency (Every X Days)		30	30	30	30
Outputs					
Flights, # of, Over the Entire Run Length		68.9	72.7	54.9	55.9
Flights per year, Simple Average	**7.17**	6.89	7.27	5.49	5.59 New Baseline
Half Width, for # of Flights over the Entire Run		3	0.48	0.34	0.47
95% Confidence Interval	**6.7, 7.6**	**6.59, 7.19**	**7.22, 7.32**		
Minimum # of Flights During the Run		39	69	53	53
Maximum # of Flights During the Run		76	75	56	58
Half Width Test, Flight Rate, (<10% PASS=GREEN)		4.35%	0.66%	0.62%	0.84%

Figure 9: Setting the Model to Perform Orbiter Periodic Overhaul at KSC Rather than in California.

Case 2 can now evolve to include the following factors:

- An increased number of days in the processing flow in the OPF, using ***10 days*** as a conservative estimate. The judgment of the analyst forms the basis for this value. The value accounts for increased vigilance and inspection activity for each orbiter returning from space.
- An increase of ***1 day*** in the integration cell activity, once again based on the judgment of the analysts. The value accounts for a higher level of activity that may result in this processing step. This step includes activity that attaches the Shuttle External Tank (ET) to the orbiter. This integration process includes thermal protection system and final spray on foam insulation (SOFI) work and can arguably result in increased activity time.
- An increase of ***3 days*** at the launch site, once again based on the judgment of the analyst. This value accounts for constraints such as daylight only launches that may last the duration of the program, External Tank loading abnormalities, specifically those that may relate to the foam and possible shedding, and lastly again the effect of generally increased constraints causing time on pad to increase.

The prior Case 2 results in the values tabulated in **Figure 10**. A Case 2 flight rate results of approximately ~ 5.13 flights per year.

GEM-FLO Case Runs March 24, 2004

Scenario>	Historical Data, Flight Rate per Year Mean	Baseline Model, with Loss of Vehicle Settings and Abort Modes Allowed	(A) Baseline Model, with Loss of Vehicle Settings and Abort Modes NOT Allowed	Case 1 - Same as "(A)" But 3 Orbiters in the Fleet Rather than 4	< Same, But Periodic Overhaul now at KSC (not California).	Case 2 - Post Columbia 10 / 1 / 3 Constraints Scenario
Settings						
Replications, # of Runs		30	30	30	30	30
Run Length (X Days)		5475	5475	5475	5475	5475
Warm up (X Days)		1825	1825	1825	1825	1825
Mission Request Arrival Frequency (Every X Days)		30	30	30	30	30
Outputs						
Flights, # of, Over the Entire Run Length		68.9	72.7	54.9	55.9	51.3
Flights per year, Simple Average	**7.17**	6.89	7.27	5.49	5.59	5.13
Half Width, for # of Flights over the Entire Run		3	0.48	0.34	0.47	0.35
95% Confidence Interval	**6.7, 7.6**	**6.59, 7.19**	**7.22, 7.32**			
Minimum # of Flights During the Run		39	69	53	53	49
Maximum # of Flights During the Run		76	75	56	58	53
Half Width Test, Flight Rate, (<10% PASS=GREEN)		4.35%	0.66%	0.62%	0.84%	0.68%

Figure 10: The Case 2 Scenario Adds 10 Days in the OPF, 1 Day in Integration and 3 Days at the Launch Pad; The Added Days in This Scenario Result in a Slight Flight Rate Decrease of about ½ Flight per Year to Approximately 5.13/Flights per Year.

As affects the completion of the ISS the dates tabulated in **Figure 11** show the accumulated effect of the additional processing days post Columbia. Whereas 3 orbiters could complete 27 launches by 2009 in Case 1, all processing assumptions being equal to pre-Columbia values, in Case 2 the ISS achieves completion in 2010 when some minor delay factors are introduced.

Basis: GEM-FLO Model Approximation Post Columbia <u>Constraints *Case 2*</u>	**Approximate ISS Completion Using a 3 Orbiter Fleet, Assuming Launch Resumption Early 2005**
20 Launches	2008
25 launches	2009
27 launches	**2010**
30 launches	2010

Figure 11: Twenty-Seven (27) ISS Launches complete in 2010 in Case 2 when Modeling Minor Additional Processing Time, vs. 2009 as in Case 1

6. Interpretation

The Case 2 “10 / 1 / 3” constraints scenario when inputted to the models provides results as expected. The addition of a given percent of days above a baseline reduces STS flight rate production per year as would very nearly have been calculated with far less sophisticated means. To add insight to the results, a second model specific to Shuttle can be used with identical scenarios. The Shuttle-Ops model (**Figure 12**) includes upwards of 200 variables that reflect on Shuttle operations in more detail than GEM-FLO. The **Figure 13** tabulation results from using both GEM-FLO and Shuttle-Ops.

Shuttle operations have achieved peaks of 8 (1992 and 1997) and more (1985, 9 launches, just prior to Challenger 51-L) launches per year, but this has never been sustained. Essentially, a 4 orbiter fleet was able to produce, under the best steady state and stable conditions about ~ 7 launches per year (1992 to 1997), or 1.75 launches per orbiter per year as a rough average. Three orbiters would produce 5.25 flights per year. *It is not surprising that the models show that slight delays, such as the 10 / 1/ 3 scenario, will normally produce only 5 flights per year. The previous scenarios show the validity and sensitivity of the models that have been created.*

The simulations do not *fully* reflect the variability that has persisted throughout the Shuttle operations history. Only that variability that would be called normal variability, the variation from one “normal” flow to another “normal” flow has been used to fit the historical data with probability distributions used in the simulations. The results presented here then are steady state, under the most normal of circumstances, representing that normal variation that as a minimum occurs from flow to flow in Shuttle operations. **Figure 14** shows one sampling of the *abnormal* variability that is, however, persistent in Shuttle operations.

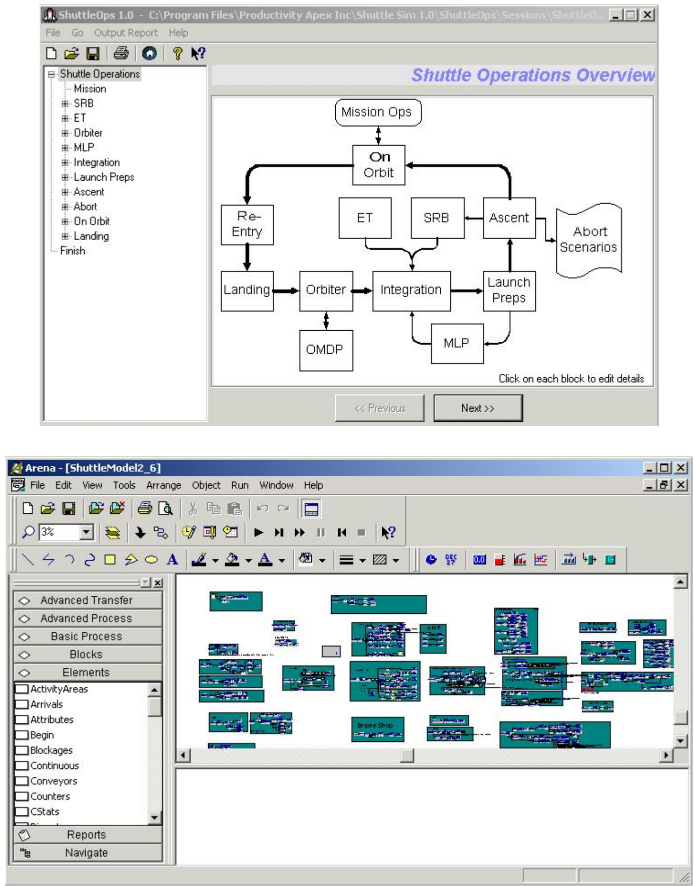


Figure 12: Shuttle-Ops Graphic User Interface and Simulation Model created with Arena ©

3 Orbiter Fleet Baselines>	GF= 5.5866		SS= 5.28	
	GF Flight Rate per Year	Delta Baseline	SS Flight Rate per Year	Delta Baseline
If Only 10 Days Added to OPF	5.2633	-5.79%	5.140	-2.65%
If Only 1 Day Added to Integration	5.5633	-0.42%	5.230	-0.95%
If Only 3 Days Added to Launch Pad	5.4733	-2.03%	5.190	-1.70%
Cumulative Effect	5.127	-8.23%	5.040	-4.55%

Figure 13: Simulation Sensitivity, One Variable Cases

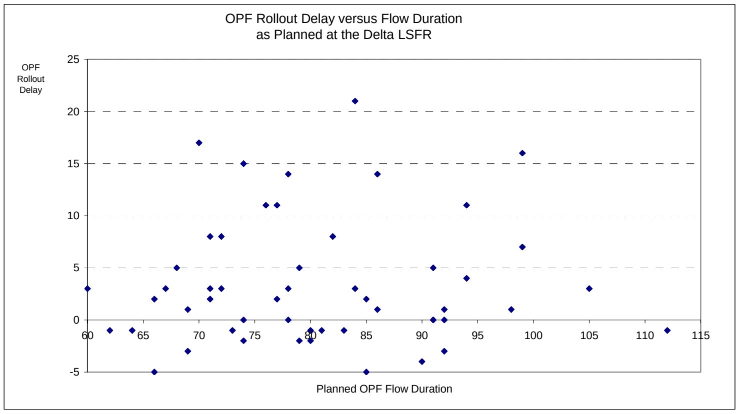


Figure 14: Variability (days) vs. STS Flow Number Designation, in Planned vs. Actual Orbiter Processing Time, Analysis Courtesy of Grant Cates, NASA Kennedy Space Center, Shuttle Processing Directorate

7. The Effect of Transferring Facilities to Next Generation Programs

The significance of flight rate and completion of the ISS leads to choices about the transition from the Space Shuttle Space Transportation System to a Next Generation (Nexgen) Space Transportation System.

Some facilities that appear of immediate interest to a Nexgen system include Shuttle Launch Pads 39, A or B and the huge Vehicle Assembly Building (VAB) Shuttle Integration Cells (**Figure 15**) of which there are also two.

A more interesting use of models such as GEM-FLO and Shuttle-Ops is to manipulate and experiment with facility resources. **Figure 16** shows the various scenarios considering a reduction in either launch pads or integration cells, or both. Due to a diminished fleet size (3 orbiters) the facilities are already under-utilized and the visible effect confirms what subject matter expertise would conclude – that the shut down or transfer of an integration cell should be looked at with more caution than the shutdown or transfer of a launch pad. *The Shuttle Safe Haven (***Figure 17***) recently constructed and operational in the Shuttle Vehicle Assembly Building, and less likely now to be called upon as only 3 orbiters and a reduced flight rate are inevitable, presents a resource that may be used instead for integration by Nexgen programs.*

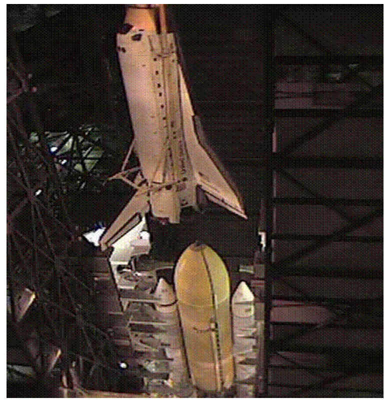


Figure 15: Shuttle Vehicle Assembly Building Integration Cell, One of Two, and Launch Pad, One of Two

	FLIGHT RATE CAPABILITY PER YEAR							
Model	Baseline, 3-orbiter fleet	Baseline, but 1 Launch Pad	Baseline, but 1 Integration Cell	Baseline, 1 Less Pad, 1 Less Integration cell	10 / 1 / 3 Case 2 "Delays" Scenario	Case 2, but 1 Launch Pad	Case 2, but 1 Integration Cell	Case 2, 1 Less Pad, 1 Less Integration Cell
GEM-FLO	5.59	5.41	4.98	4.94	5.13	5.01	4.89	4.89
Shuttle-Sim	5.28	5.12	4.77	4.69	5.04	4.93	4.6	4.58

Figure 16: Flight Rate Capability per Year as Indicated by Simulations for Various and Cumulative Factors

Figure 17: Shuttle Safe Haven, a Possible Nexgen Integration Cell; the Lack of Capability Other than Crawler-way and Shelter May Prove an Asset to a Program Seeking Simplified System Design and Reduced Infrastructure

8. Summary Review – Decreased Flight Rates and ISS

Definitions are required to interpret the results and apply them to decision making relevant to the Presidential Vision for Space Exploration. Offering some definitions:

DEFINITIONS:

- "Best Case / Success Oriented": The term may be used for results from scheduling that is date driven and reflects typical experience. Typical NASA manifests planning such as Figure 18 may be referred to this way.

- "Best Case / Probable": The results obtained from stochastic simulations such as GEM-FLO or Shuttle-Ops may be referred to this way. Normal probabilistic variations are included, but extremely off nominal events are excluded.

The Shuttle *best case / probable* operation can support between 5.28 and 5.59 launches per year judging by the simulations used previously. Slight delays, wholly reasonable in scope, make these figures between 5.04 and 5.13 launches per year – again *best case / probable*. Best case assumes no significant anomalies from the resumption of Shuttle operations through to the end of the program.

A third definition other than best case / success oriented or best case probable is required to understand the simulation results further *as ceilings above which flight rates are unlikely.*

It is reasonable to conclude that "anomaly" delays are not only inevitable, but far worse than those explored here. Consider the example of launch pad constraints (**Figure 18**). A delay post-Columbia will not only add days to account for the delay itself. Any delay, due to closed launch windows and other constraints, can easily push one delay into overlap with another delay – a "no launch period" window for example.

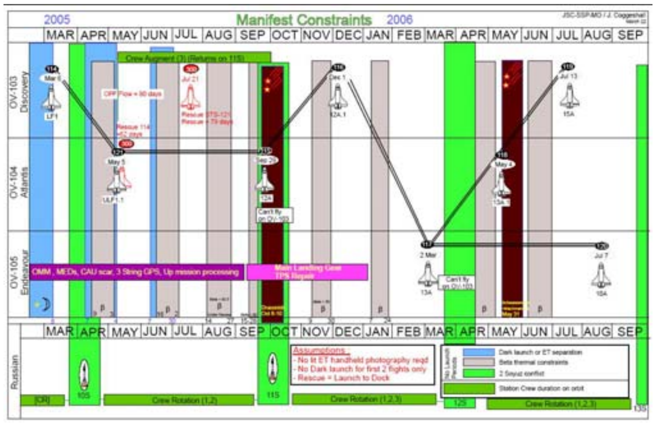


Figure 18: A Possible Shuttle Post-Columbia Launch Schedule (for Planning Purposes Only)

Intangible post-Columbia effects that are not modeled here include:

- Historically proven variability above and beyond normal variability:
  - Examples here in the past include leaks in the 1989-1990 time-frame, electrical wiring problems in the late 1990's, and most recently post-Columbia rudder-speed brake anomalies.
  - This variability has all been unexpected variation resulting in months of fleet grounding.
  - Mission complexity has also introduced extreme unexpected delays into Shuttle processing flows (e.g. STS-41, Planetary Mission).
- Increased engineering conservatism
- New hire additions to the work-force, lack of corporate memory
- An aging fleet
- An aging infrastructure
- Political considerations forcing reviews, studies and often re-designs of either hardware/software, processes or organizations

Although anomaly data for Shuttle is a scant data set, given low historical launch rate overall, a third definition looking to plan for the anomalous delay every few years or so could be called a "Robust / Risk Reduced" result.

DEFINITION:

- "Robust / Risk Reduced": The result obtained by considering the most dynamic aspects of a system, beyond normal variation.

A "Robust / Risk Reduced" estimate of flight rate for Shuttle considering ISS completion might be, supported by the upper ceilings reviewed previously:

ISS completion, if only at 2 launches in 2005, and ~ 4 per year thereafter, easily pushes 27 launches into 2012, 2 years beyond the 2010 "goal" established in the Presidential Vision for Space Exploration.

9. Increasing Flight Rate ***Probability***

Simulations may also be used to study the effects of *increased* launch rate. Within the perspective of the Presidential Vision for Space Exploration, costs and safety considerations for NASA extend beyond the boundaries of the Shuttle program. *Specifically, how much would it reduce NASA costs and increase safety if the ISS could be completed by 2010 with confidence, enabling a smooth yet faster transition to a new system?*

As an example of time being as important as cost, the delay in beginning the Shuttle program in the late 1970's translated dollar for dollar into amounts typically attributed as a "development over-run". Once an organization is readied for operations, a delay in beginning operations does not make the organization go away and reappear again 2 or 3 years later.

Figure 19 shows the NASA plan for the new Space Exploration initiative. Should the operations for Shuttle have to continue, the difference in costs, designated "A" for purposes of this analysis, equates into either (1) a decrease "B" for the exploration initiative (so as to arrive at the same overall budget line) or (2) an increase (or over-run) "C" in overall expenditures if the exploration initiative is held as planned. The rough order value of the difference equals approximately $3B in a given year such as FY 2012, which equates to the Shuttle budget *not* having shut down and operations more or less proceeding as usual to accomplish the task of finalizing ISS launches.

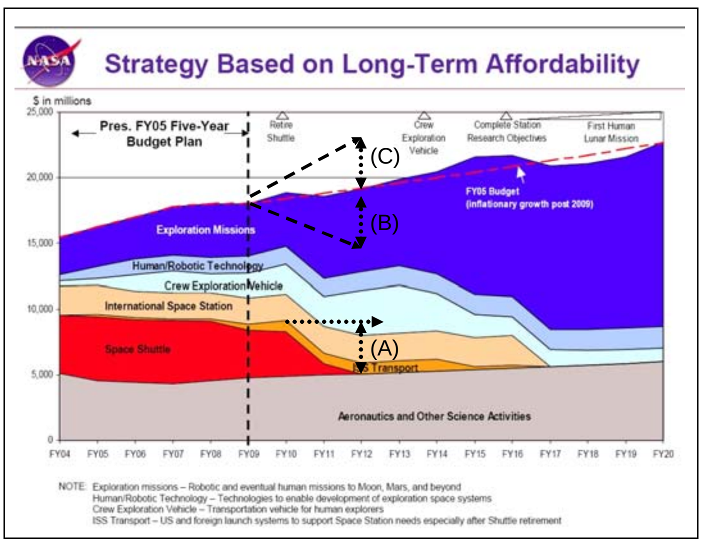


Figure 19: NASA Plans for the New Exploration Initiative Link the Decline in Current Operations to the Surge in Future Operations

Increasing Shuttle Flight Rate ***Probability*** can be quickly viewed via simulations by addressing the OPF flow surfaced previously as key in overall flight rate capability. A shift of minus 14 days in OPF flow time (-14+the established OPF distribution, GAMM(1.273, 66.267)) results in the values in **Figure 20**.

A more sophisticated analysis, beyond the capability of GEM-FLO and Shuttle-Ops, would tabulate probabilities of meeting cumulative launches and dates by specific points in the future.

FLIGHT RATE CAPABILITY PER YEAR	
Model	**3-Orbiter Baseline *minus* 14 days in OPF**
GEM-FLO	6.16
Shuttle-Sim	5.38

Figure 20: The Effect of Reduced OPF Flow Time on Flight Rate

Any attempt to increase flight rate, while maintaining and improving safety, translates into 1 of various approaches that can be taken as “business case analogies”

Strategy 1-A business can increase the absolute amount of profit by increasing sales. A business making $3 Million dollars in profit on $100M in sales must double sales to $200M in order to amass $6 Million dollars in profit.

Strategy 2-Enterprise wide thinking focuses on decreasing the transaction time or cost in modern business improvement models. For example, reducing costs by a dollar translates dollar for dollar into profit whereas increasing sales only results in a marginal % increase. Improvement here would focus on enterprise resource planning (ERP) and supply chain management (SCM).

Strategy 3-The enterprise can focus on increasing the profit from high margin products or on improving only the operations associated with high margin products, thereby increasing profit where it counts the most.

By analogy, Shuttle operations can use subject matter experts to pursue **Strategy 1**, diffusely improving the visible processing and engineering activities and picking up the cumulative timeline improvements. Because generalized continuous improvement strategies tend to attack visible activity broadly, and much of this activity if not most can be parallel and non-critical path, such a strategy, as with “increasing sales” is only likely to yield a % percent actual critical improvement from the sum of all of the improvements themselves.

Strategy 3 often results from the realization that diffuse results from **Strategy 1** are insufficient to translate into tangible, significant results. Critical paths are sought out and large chunks of a few activities are more dramatically re-designed to obtain the objective. For current Shuttle operations such an approach would have to find jewels of un-exploited time-line waste, a strategy that assumes that dozens of previous such efforts have somehow overlooked significant product or process improvements. Significant product improvements, given the Shuttle reviews, certification, and oversight requirements for any changes, may not represent improvements that can be implemented in time to make a difference in relation to Nexgen transitions and ISS completion. Analysis efforts here, building on the simulation work to date, could prove fruitful, but risk finding few areas of significance that can also be executed in time to make a difference to events within the next 5 years or so.

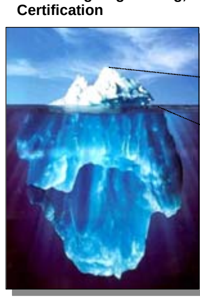
Strategy 2 is left. All Shuttle processes or "activity" ultimately includes the interaction or transaction costs of the visible activity (such as preparing an engine for flight) with the less visible activity – the supply chain and enterprise that plans, enables, and supports the visible activity.

Figure 21 shows the cost of the supply chain and the transactions between visible and less visible activity most clearly. The amount of Shuttle operations below the tip-of-the-iceberg that can be improved is significantly larger than that above the waterline. (As Willie Sutton would say, why did he rob banks…)

NGLT
Next Generation Launch Technology

STS Recurring Cost Perspective

- **"Direct" (Most Visible) Work <u>Drives</u> Massive (and Least Visible) Technical & Administrative Support Infrastructure**
- **<u>Example</u>: Direct Unplanned Repair Activity <u>Drives</u> Ops Support Infra, Logistics, Sustaining Engineering, SR&QA and Flight Certification**



Direct (Visible) Work
"Tip of the Iceberg"
+
Indirect (Hidden)
+
Support (Hidden)
Recurring Ops $$s

STS Budget "Pyramid" (FY 1994 Access to Space Study)

Generic Operations Function	Total $M FY94	*Total (%)*	
Elem. Receipt & Accept.	1.4	***0.0%***	~10%
Landing/Recovery	19.6	***0.6%***	
Veh Assy & Integ	27.1	***0.8%***	
Launch	51.5	***1.5%***	
Offline Payload/Crew	75.9	***2.3%***	
Turnaround	112.3	***3.3%***	
Vehicle Depot Maint.	237.5	***7.1%***	~20%
Traffic/Flight Control	199.4	***5.9%***	
Operations Support Infra	318.6	***9.5%***	
Concept-Uniq Logistics	842.7	***25.1%***	~70%
STS Ops Plan'g & Mgmnt	1477.4	***43.9%***	
Total ($M FY94)	**3363.4**	***100.0%***	
Percent	**100.0%**		

11

Figure 21: Courtesy Carey McCleskey, NASA KSC, Systems Engineering Office, Root Cause Analysis Project

Figure 22: ERP and SCM Implementations,
Part One: Doing Too Much Too Soon, Joseph Strub - April 8, 2004,
http://www.technology-evaluation.com/Research/ResearchHighlights/Erp/2004/04/research_notes/MI_ER_XJS_04_08_04_12.asp

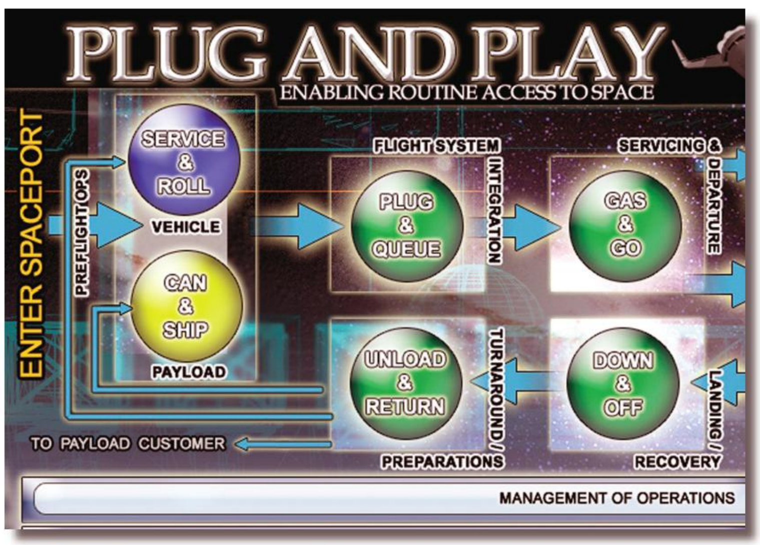


Figure 17. Plug & Play vision of spaceport operations

Figure 23: From the Advanced Spaceport technologies Working Group, Baseline Final Report, November 2003

The relationship between this iceberg and modern supply chain economics can be seen in comparing **Figure 21** to **Figure 22.**

NASA has already begun the Integrated Financial Management Program [2](IFMP) to address a portion of Enterprise Resource Planning (ERP) applicable to the acquisition, financial and procurement processes so important to an agency that [3]contracts out most of its budget.

Strategy 2 "Enterprise" level improvements would need to build and leverage off of current NASA ERP efforts to address transaction level

[2] IFMP NASA Internal Web Page at: http://ifmp.msfc.nasa.gov/
[3] "NASA Quality – Workmanship" Tom Whitmeyer, Manager, Agency Quality Program, June 26, 2001, Workmanship Team Meeting, Chart 2.

activity between visible processing tasks that prepare a Shuttle for launch and less visible support tasks.

These transaction improvements would orient around having the right information, at the right time and the right place. Transaction examples include:

- Scheduling
- Work control
- Sustaining engineering
  - Especially including information flow, task generation, requirements generation, drawing and engineering information
- Planning
- Documentation
- Analysis
- Logistics
  - Especially supporting scheduled and unscheduled process activity
- Work verification
- Configuration control

Separately, integration of the NASA supply chain with vendor / contractor supply chains is integral to all the prior areas.

Recent studies such as the Advanced Spaceport Technologies Working Group [4](ASTWG), a National effort focused on Spaceport infrastructures, corroborate the need for investment in these supply chain areas. **Figure 23** envisions modernized, future spaceport operations. Improvement at the ERP and SCM levels is crucial to Spaceport improvement. Potentially, such a "transaction" focus on areas below the tip-of-the-iceberg would be able to avoid the pile-up (**Figure 19)**, due principally to Shuttle flight rate capability and post-Columbia factors.

[4] ASTWG : http://artwg.ksc.nasa.gov.; Advanced Spaceport Technologies Working Group Baseline Report, November 2003

10. Conclusions and Recommendations

1. As is, post-Columbia Shuttle operations are likely to complete the ISS by 2010 only within a "Best Case / Success Oriented" view. The slightest perturbation will make even a "Best Case / Probable" estimate (a probabilistic estimate) push beyond 2010. A "Robust / Risk Reduced" estimate can easily translate into a 2012 date and beyond for the Shuttle to complete 27 launches. Further work is required on this later as relates to post-Columbia processing effects and constraints which continue to evolve even as of this writing.

2. To avoid a multi-billion dollar pile-up/ confluence (**Figure 19)** of 3 programs, Shuttle, ISS and the new Exploration Initiative, efforts should immediately commence to improve the posture for the 3-orbiter Shuttle post-Columbia flight rate capability.

3. Possibly, the most advantageous investment for avoiding multi-billion dollar delays, over-runs or lost opportunity will be in the lower levels of Shuttle program operations, at the Enterprise Resource and Supply Chain levels. This will assure that activity (hands-on, processing, launch work) that process Shuttle systems have disappearing and or reduced delay / transaction times originating in the supply chain network. Further work in critical paths, complemented by simulation, may yield additional results but be complicated by the nature of changing physical or technical attributes of a flight or associated ground system.

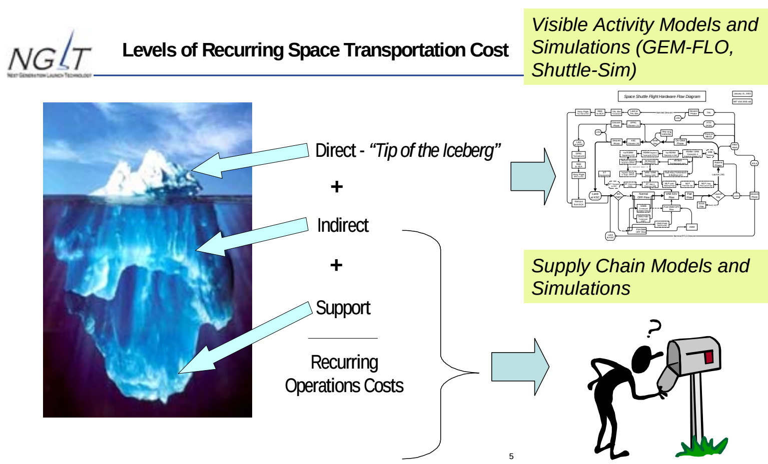


Figure 24: On the Need for a Next Step in Modeling and Simulation of Complex Space Transportation System Operations

4. Investments in the Shuttle ERP and SCM will directly translate into savings in the Nexgen program / new Exploration initiative. This would not be the case with Shuttle specific (and unlikely) “critical path” type approaches the life of which would be limited to the Shuttle configuration and complexities.

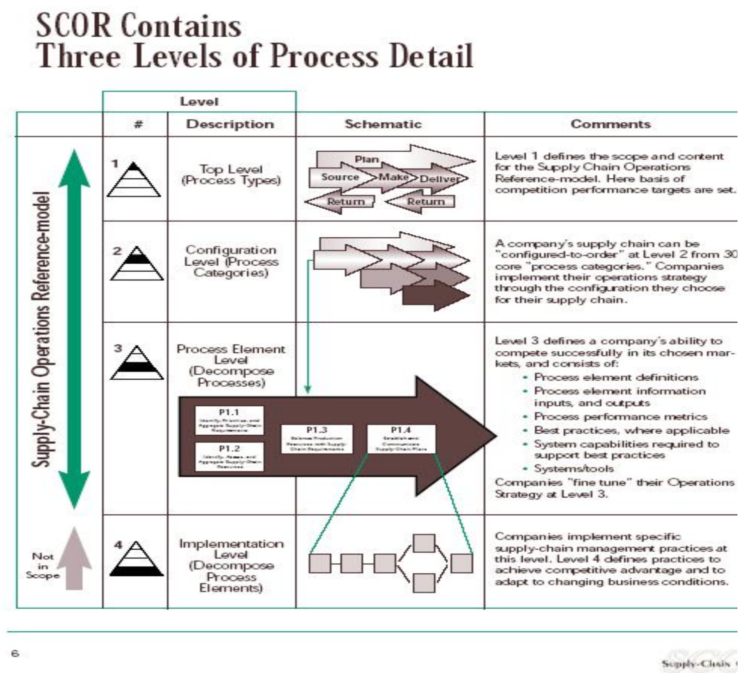


Figure 25: SCOR: Supply Chain Operations Reference Model

5. It is crucial to further understand and quantify the NASA Shuttle operations enterprise and the associated supply chain. While directly visible activity has been modeled and demonstrates an ability to capture and reflect expert knowledge in easy to use tools, no corresponding work has occurred in the Shuttle operations supply chain (Figure 24). Methods that can be immediately explored include, but are not limited to, the use of the [5]Supply Chain Operations Reference (SCOR) Model (Figure 25).

[5] Supply-Chain Operations Reference-model,
Overview of SCOR Version 5.0,Supply-Chain Council, Inc. 303 Freeport Road, Pittsburgh, PA 15215, www.supply-chain.org